APPENDIX B: Environmental Flows Assessment for the lower South Esk River d/s Glen Esk Bridge

1. Description of study reach

This reach is located on the lower South Esk River immediately downstream from the Glen Esk bridge (Figure B1). It is situated approximately 10 km downstream from the point where the South Esk River leaves the Fingal Valley at the Llewellyn property. This reach was chosen by Davies and Humphries (1996) as being a reach that was considered to be representative of the lower South Esk River system, and one of the locations where they undertook a study to derive minimum flows for the river. Although the elevation, hydraulic and biological data from that study was collected for use in a different assessment methodology, the data has been re-worked for use in the updated 'Tasmanian Environmental Flows Framework' (TEFF) method now being used by DPIW.

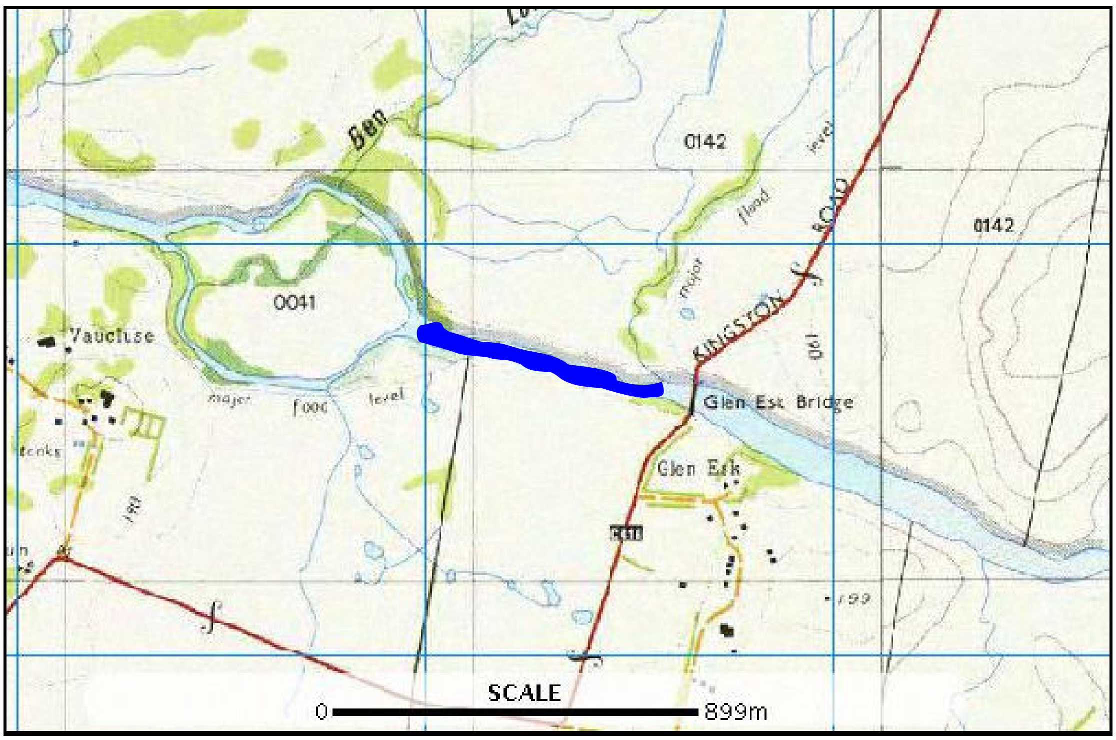

Figure B1: Map showing the location of the environmental flows study reach at Glen Esk Bridge (TASMAP 5237).

In this area the river is still confined within a well-defined channel and has not yet begun to develop the meandering form that occurs another 10 km further downstream and is present at the 'Neck of Bottle' reach. Despite this the gradient of the river-bed has substantially declined. The river at this location consists of long pools ('broadwaters') connected by sequences of extended runs and shorter riffles. The dominant habitat in this area of the river is run habitat and the substrate of the river is primarily composed of cobble and boulder material with a moderate level of silt infill. During the warmer months this is heavily overgrown by aquatic macrophytes* and algae. The riparian zone of the river is commonly dominated by willow (*Salix* spp.)

* for a definition of these words or terms, see the Glossary in the main report.

and other introduced plants, but in some areas contains remnant native riparian* plant communities.

The study reach examined by Davies and Humphries (1996) and used for this assessment covers approximately 800 m of river encompassing run and riffle habitat. The width of the active river channel (which is frequently inundated by small floods and freshes) is between 20 and 45 m, and ranges in complexity from a relatively simple channel with benches on one side (as represented in the cross section in Figures B2a) to a more complex bisected channel (Figures B2b). The estimated water depth at zero flow ranges between 0.1 m and 1.2 m throughout the reach.

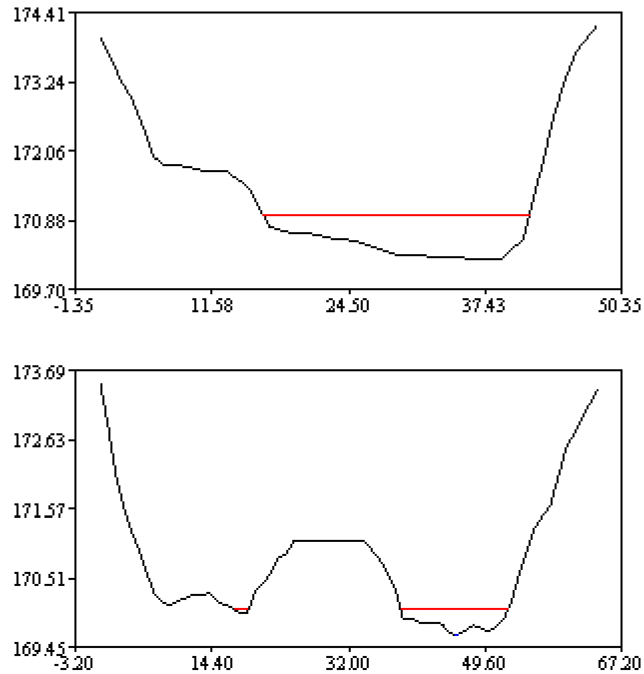

Figure B2a&b: Two cross-sections of the South Esk River at Glen Esk. The red line depicts modelled water level at zero flow.

2. Environmental Values and Objectives

Although the CFEV database indicates that the South Esk River from Longford to Avoca has a low degree of 'naturalness'* (CFEV 2005), the reach of river encompassed by this assessment lies within a section that has been defined as having 'medium' to 'very high' conservation management priority*. The CFEV database highlights a number of environmental values that pertain to this classification, and these generally relate the remnant vegetation communities that are present alongside the river and the assemblage of fish that is likely to inhabit the river. There are also a number of special values that relate specifically to the aquatic ecosystem, namely;

- Endemic caddisfly species
- South Esk freshwater mussel *(Velesunio moretonicus)*

* for a definition of these words or terms, see the Glossary in the main report.

- High priority riparian and aquatic plant species (*Poa* grassland and Purple loosestrife) and communities
- Platypus *(Ornithorynchus anatinus)*

As well as these, other important biophysical classes that are highlighted within CFEV relate to the geomorphology of the river system, freshwater crayfish that occur within the region and the characteristic fringing aquatic plant communities that occur in the South Esk and Macquarie river systems. All of the information obtained from the CFEV database and used to develop environmental objectives for the reach are presented and discussed within the broader context of the South Esk catchment in Chapter 2 of the main report.

Summarised in simple terms, an environmental flow for the lower reaches of the South Esk River should aim to provide sufficient water to meet the needs of;

- the fish community occurring in the river (particularly native fish),
- aquatic and riparian plant communities within the river corridor,
- endemic freshwater biota,
- riverine productivity and basic foodweb structure, and
- geomorphic processes that maintain instream habitat.

Based on this information, Table B1 presents the main environmental objectives that an environmental flow should address and the flow components that are required to achieve the objectives. Further information about these flow components, such as their frequency, timing and magnitude, are provided in Chapter 2 of the main report; that report also provides references to the published literature that illustrate the importance of these flow components in riverine ecosystems. These are similar to those that have been developed for other study reaches in the middle and lower river system (Ormley and Neck of Bottle), as all of these reaches have some values and characteristics in common.

Table B1 clearly shows that environmental flow provisions for this section of the river should not simply focus on providing a 'minimum flow' during the dry months, but requires adequate provision of water over the entire flow regime. However, prior to undertaking the environmental flow assessment, the impact of current water use on the flow regime at this reach should be examined. This topic is briefly covered in the next section.

Table B1: Environmental objectives of the environmental flows assessment for the lower South Esk River at Glen Esk, and important components of the flow regime that support the objectives.

Environmental objectives for the South Esk River at Glen Esk	Flow components that are important* in maintaining the environmental objectives and their scientific basis
Maintain healthy populations of native fish	• Seasonal occurrence and magnitude of freshes and minor flood events that act as triggers for migration and dispersal • Baseflows that provide riverine connectivity during summer • High flow events that flush out fine sediments and rejuvenate and maintain spawning habitats
Maintain existing macroinvertebrate community diversity and abundance	• Seasonal pattern of change in baseflow and flow variability; frequency and occurrence of freshes and high flow events to maintain mechanisms of 'drift' and dispersal. • Bankfull and overbank flows during winter and spring to maintain riparian vegetation as sites for breeding and oviposition, and source of instream wood and leaf-packs for food and habitat • Minimum flows to support adequate instream habitat and maintain wetted leaf-packs during dry months
Provide habitat of good quality for instream biota	• Summer and autumn freshes to control unpalatable and habitat-smothering filamentous algae • Flood events that import and move large woody debris, maintain bank undercuts, redistribute fine organic matter and flush fine sediments from riffle macropores • Minimise the duration of extreme low-flow events that may impact on the habitat of endemic freshwater mussels
Maintain healthy instream macrophyte communities and current spatial coverage & distribution	• Maintain wetting/drying regime in shallow, fringing lateral benches and small riparian wetland patches • Maintain seasonal flushes that prevent excessive and prolonged smothering by epiphytic algae
Maintain productivity and benthic metabolism of riverine ecosystem	• Water level in pools and runs that maintain hydraulic head above riffle zones and sustain flow through interstitial pores • Seasonal flow events that flush out attached algae, mobilise bed material and re-set biofilms
Maintain populations of platypus	• Summer low-flows and winter high flows for foraging and maintenance of leaf-packs • Flows that maintain riparian habitat that is suitable for burrows
Sustain existing riparian and floodplain vegetation	• Bankfull flows and larger flood events to recharge local groundwater system and provide access to groundwater during dry periods • Freshes and floods to stimulate re-generation through disturbance, disperse seeds and aid recruitment
Maintain current geomorphic character and processes	• Flood events that mobilise varying size-fractions of bed material, create 'new' patches of instream habitat and physical features and maintain scouring and transport processes • Overbank flow events that maintain larger-scale floodplain features and processes

*For a more detailed list and explanatory text, see Chapter 2 of the main report.

3. Impact of current water use on flows

A risk assessment has been carried out in the main report (Chapter 4). This was based on an analysis of the alteration in hydrology that has occurred as a result of water use in the South Esk catchment along with a conceptual understanding of the river system. The hydrological analysis of the river at Glen Esk (summarised in Chapter 3 of the main report) shows that the current flow regime is essentially unmodified, and that the combined impact of water use in the middle and upper catchment has only caused some change to the low-flow component of the flow regime. Subsequently, the following environmental flow assessment for the South Esk River system in the vicinity of Glen Esk focuses on providing information on what might constitute an environmentally appropriate minimum flow as well as flood-flow provisions that are likely to maintain the identified environmental values. Given that the current level of water abstraction in this sub-region presently poses minimal risk to existing environmental values, the recommendations made in the following sections are aimed at preserving these values even if water use increases in this region in the future.

4. Minimum flow analysis

Chapter 5 of the main report provides details about the methods used to conduct this assessment and the analytical approach used to derive the environmental flow recommendations. The minimum flows assessment is primarily intended to provide water for instream flora and fauna and maintain environmental funtion during drier periods of the year. To do this, information on the channel morphology and habitat preferences of instream biota are used as input to a hydraulic-habitat modelling procedure.

No topographical or biological information was collected from this reach of the South Esk River during this study. Aside from fish community information collected during recent surveys in the upper river system, the majority of biological information and all of the channel survey data that was used for this assessment, was taken from earlier work conducted at this reach during early 1990’s as part of a minimum flow assessment project (Davies & Humphries, 1996). This early project, which was jointly funded by the National Landcare Program, the Federal Water Resources Assistance Program and the Department of Primary Industries and Fisheries, was the first study in Tasmania to examine minimum flow requirements of Tasmanian rivers. The study examined reaches in the Macquarie, Meander and South Esk rivers. Although this early study used a different approach to the determination of minimum flows for these rivers, much of the data that was collected was re-structured for use in the present assessment, including the habitat-flow relationships that were developed.

It must also be mentioned that as the earlier study was focussed solely on the provision of minimum flows for these rivers, the surveying data that was collected did not always extend very far up the riverbank. As a consequence of this, the hydraulic simulation model constructed for the present study cannot effectively predict water levels when flows at this reach of the river exceed about 14 $m^3.s^{-1}$.

For an assessment of the minimum flow requirements for the Glen Esk reach, habitat-use information (primarily depth and velocity preferences) for the following main components of the aquatic fauna were used:

- Native and introduced fish species (Galaxias, pygmy perch, blackfish, short-finned eels, and brown trout),
- General abundance of macroinvertebrates,
- The South Esk freshwater mussel *Velesunio moretonicus*,
- The freshwater crayfish (*Astacopsis franklinii*), and
- Platypus (*Ornithorynchus anatinus*)

Because each of these components of the faunal community have different habitat and flow preferences, and therefore different habitat-use curves, an attempt was made to combine the curves for each to provide an estimate of habitat availability with changes in flow for the assemblage as a whole. However it was found that fauna that live predominantly above the bed of the river and are more mobile (fish, crayfish and platypus) tend to prefer water depth and velocity conditions that occur under lower flows. In contrast, the less mobile fauna (invertebrates) were generally more tolerant of greater water depths and velocities. In developing recommendations for minimum environmental flows for the Glen Esk, it was therefore decided to examine the habitat-use information of these two different suites of fauna separately.

The habitat-use curves for finned fish, crayfish and platypus were combined to form a 'mobile' fauna assemblage curve (Figure B3 below). The curve includes the habitat preferences for adult and juvenile brown trout (*S. trutta*). Although brown trout are an introduced species, the exclusion of this species did not significantly alter the shape or size of the rating curve.

The species-specific curve for southern pygmy perch (*Nannoperca australis*), which is not shown here, suggests that habitat availability declines when flows exceed about 5 $m^3.s^{-1}$. This reflects the preference of this species for the shallow and very low velocity environment provided by fringing aquatic plant. Although the model predicts that under higher flows habitat for this species declines, like most other fish pygmy perch are likely to find refuge in slack-waters and newly-created, shallow water habitat.

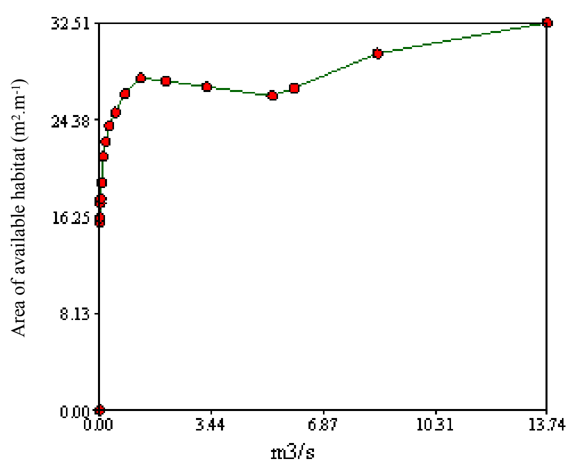

Figure B3: The 'mobile fauna' assemblage habitat-use curve for the Glen Esk reach on lower South Esk River. This rating curve shows how the area of available habitat for this assemblage as a whole (in units of square metres per metre of river length), varies with changes in flow. The curve is derived from the amalgamated information on habitat preferences for all native and introduced fish, crayfish and platypus.

The curve shows that the greatest amount of area available (shown in units of square metres of habitat area per metre of river length) for this suite of fauna exists when flow is ≥1.5 $m^3.s^{-1}$. The maximum amount of habitat available for the assemblage is 32.5 $m^2.m^{-1}$ which occurs at the maximum flow of the rating.

The habitat-use curves for freshwater mussels and macroinvertebrate abundance have been combined to produce a 'benthic' fauna assemblage habitat-use curve (Figure B4). The curve, which is much more linear than that for the mobile fauna, shows that the habitat for this community is very limited at flows less than 1.2 $m^3.s^{-1}$, after which it increases rapidly. The lack of habitat for the benthic fauna assemblage at flows below 1.2 $m^3.s^{-1}$ is primarily due to the lack of instream habitat for freshwater mussels. It should be noted that suitable habitat for benthic fauna is generally lower than occurs for mobile fauna throughout the range of flow covered by the habitat availability curve, but particularly at flows below 10 $m^3.s^{-1}$.

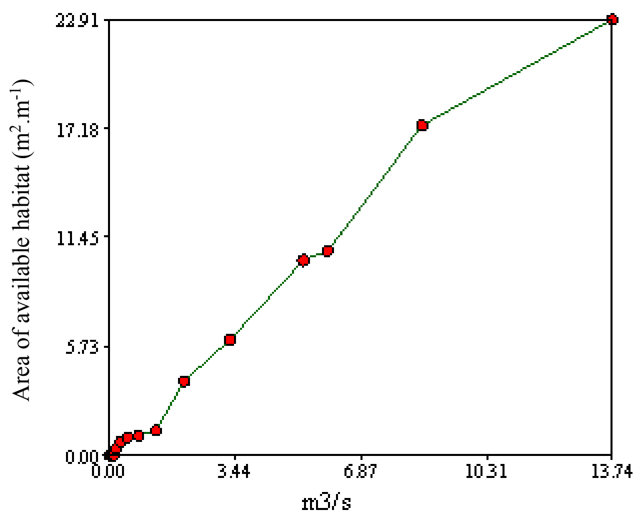

Figure B4: The 'benthic fauna' assemblage habitat-use curve for the Glen Esk study reach on lower South Esk River. This rating curve shows how the area of available habitat for this assemblage as a whole (in units of square metres per metre of river length), varies with changes in flow. The curve is derived from the amalgamated information on habitat preferences for the South Esk freshwater mussel (*V. moretonicus*) and general macroinvertebrate abundance.

Using each of the rating curves shown above, a time series of habitat availability was generated from the 'natural' flow record for the South Esk River at this location. The 'natural' flow data was produced from the hydrological model that has been developed for the South Esk catchment under the NAP program. For this study, 43 years of daily average flow data was used as this is the period that has the best record of rainfall and evaporation data upon which the predictions of flow are made.

Because this component of the assessment is focussed on the low-flow aspect of the water regime, a procedure called 'baseflow separation' was performed (using the Lyn-Hollick filter for digital baseflow separation, with an alpha-value of 0.97). The resulting baseflow time series was then used to generate a time series of changes in available habitat within the river using the rating curves shown above. The data that is produced in this manner can then be summarised and plotted in the form of a chart showing the average amount of habitat available on a monthly time-step (Figure B5). It shows that a high proportion of preferred habitat remains available to the mobile fauna assemblage throughout the year, when only baseflow data is used as the predictive variable. Habitat availability for the benthic fauna assemblage undergoes a more substantial seasonal change, and is clearly restricted by low baseflow during the drier months.

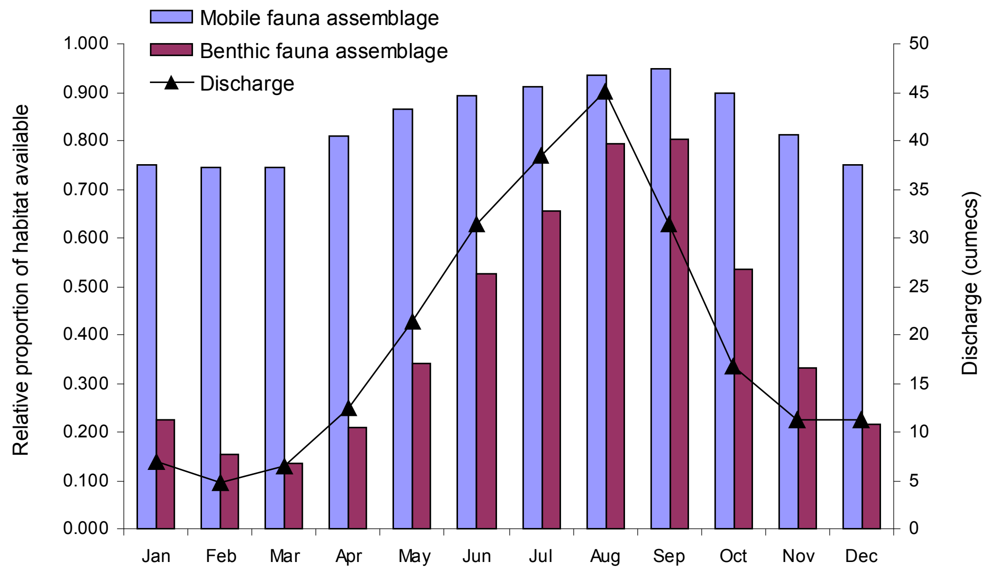

Figure B5: Graph showing the average proportion of baseflow stream area available as preferred habitat for 'benthic' fauna and 'mobile' fauna (bars) alongside changes in monthly average 'natural' flow (line) in the lower South Esk River at Glen Esk. The proportion of habitat available is a function of the area that is actually available under average monthly baseflow relative to the maximum area this is available at the preferred flow.

From this comparison it is clear that during the period from December to April, when average baseflow falls below 4 $m^3.s^{-1}$, habitat for benthic fauna is markedly reduced. It also needs to be recognised that unlike the species included in the 'mobile fauna' assemblage, during these times the benthic fauna are less able to move out of areas that are drying out and take refuge in the remnant pools. It is therefore appropriate that during the dry months the minimum flow recommendations are aimed at providing adequate habitat for the 'benthic fauna' assemblage.

To determine a minimum flow level, the time series of habitat area available for 'benthic' fauna (derived from the conversion of the 43-year modelled record for 'natural' baseflows), was statistically analysed. The daily data for each month was aggregated and from these monthly subsets of data, percentiles of habitat availability were computed. The outcome of this analysis is graphically presented in Figure B6. It shows the monthly change in selected percentiles of habitat area available for the 'benthic fauna' assemblage. From the graph it is clear that there is a significant decline in habitat availability for benthic fauna during February and March, and that the 75th percentile throughout the summer months is at or near to 5 $m^2.m^{-1}$. This is less than one quarter of what is available during the winter and spring months.

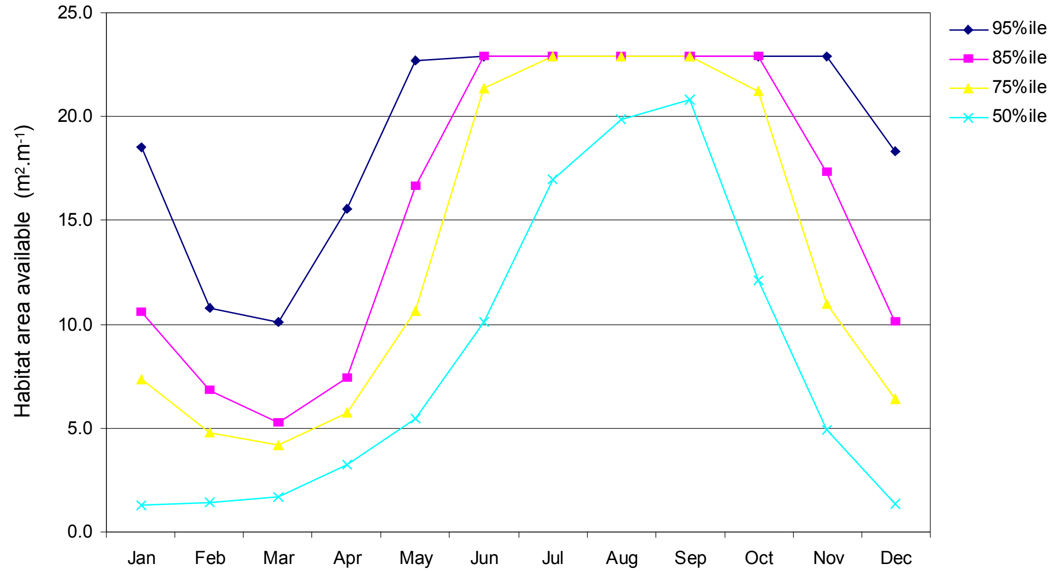

Figure B6: Graph showing the monthly change in selected percentiles of habitat area available for the 'benthic' fauna assemblage in the South Esk River at the Glen Esk using modelled 'natural' baseflows from 1960 to 2003.

Table B2 provides an indication of the flows (as daily average flow) which provide varying amounts of habitat for macroinvertebrate communities within this study reach. Knowing what flows will provide what percentage of instream habitat for benthic fauna provides a good basis for making recommendations for minimum environmental water provisions. This recognises that the benthic fauna assemblage is the component of the aquatic community that is most likely to be limited by low flow conditions.

Table B2: Monthly 85th, 75th and 50th percentiles of instream habitat for 'benthic fauna' at Glen Esk derived from 'natural' baseflow data, and the corresponding flows that provide these amounts of habitat.

MONTH	85%ile habitat ($m^2.m^{-1}$)	Flow that maintains 85% of habitat ($m^3.s^{-1}$)	75%ile habitat ($m^2.m^{-1}$)	Flow that maintains 75% of habitat ($m^3.s^{-1}$)	50%ile habitat ($m^2.m^{-1}$)	Flow that maintains 50% of habitat ($m^3.s^{-1}$)
Jan	10.60	5.73	7.35	3.92	1.25	1.20
Feb	6.80	3.63	4.81	2.58	1.43	1.30
Mar	5.29	2.87	4.18	2.18	1.67	1.37
Apr	7.41	3.95	5.74	3.05	3.24	1.85
May	16.62	8.27	10.67	5.80	5.44	2.92
Jun	22.91	13.71	21.34	12.27	10.11	5.23
Jul	22.91	13.71	22.91	13.71	16.98	8.40
Aug	22.91	13.71	22.91	13.71	19.91	10.94
Sep	22.91	13.71	22.91	13.71	20.82	11.76
Oct	22.91	13.71	21.24	12.17	12.10	6.50
Nov	17.31	8.62	11.00	6.10	4.93	2.63
Dec	10.09	5.20	6.41	3.42	1.32	1.28

However, in developing a minimum flow recommendation for this section of the river, consideration must also be made of flows that maintain connectivity between pools and broadwaters during dry periods, as broadwaters are significant features of the lower South Esk River system and contain significant environmental values. As well as maintaining connectivity, the other main environmental consideration in this area is wetting of lateral benches within the river channel which contain extensive macrophyte beds. Earlier environmental flow studies conducted at this location (Davies and Humphries, 1996) suggested that flows of less than 2 $m^3.s^{-1}$ posed a high to very high risk to macrophyte habitat (and hence macroinvertebrate abundance and diversity within this habitat). For complete inundation of all lateral instream benches (to a depth ≥0.05 m), a discharge of about 6 $m^3.s^{-1}$ is needed. This is clearly a significant flow, and a further examination of the data shows that an estimated 50-70% of lateral bench area is 'wetted' under a much lower flow of about 2.5 $m^3.s^{-1}$. In providing this 'range' of bench inundation flows it is recognised that the macrophyte community that inhabits this area is a product of variable wetting and drying, and does not require permanent inundation to exist. Indeed, a variable water level regime promotes diversity in these plant communities (Brock, 2000) and is a requisite for their long-term health and viability.

4.1 Recommendations for minimum flow provisions

Although the data in Table B2 provide useful information on what amount of instream habitat is available under different low flow conditions, using this information to make recommendations regarding minimum flow allocations requires some discussion of ecological consequences.

The 'habitat availability' values in Table D2 were calculated using baseflow data that were extracted from the 'natural' flow data provided by the hydrological model for the catchment. These baseflow data do not contain flow variability that is associated with surface runoff and they represent minimum flows that would occur in the absence of agricultural water extraction.

Given the method used to generate the habitat availability data, it is clear that adopting a minimum flow that aims to maintain 85% of instream habitat (the 85% habitat maintenance flow) is the most conservative alternative and likely to provide the best protection for instream ecosystem values. At the other end of the spectrum, adopting a minimum flow level that will maintain only 50% of instream habitat is less likely to sustain a healthy and productive aquatic ecosystem. Whilst the rating curve for the mobile fauna indicates that these flows (1.5-2.5 $m^3.s^{-1}$) will maintain a reasonable amount of habitat for the mobile fauna assemblage, in particular pygmy perch, there is a greater risk that these flows will provide insufficient habitat to maintain invertebrate abundance and diversity.

The rationale for adopting a 'median condition' has been used in other environmental flow studies where researchers have sought to establish a 'standard' or 'reference' condition. Adopting a median value recognises environmental variation, and the balance between extreme stress and abundant provision. Whilst adopting a median is less conservative than adopting an 85^{th} percentile, if it is considered as an 'absolute limit' (i.e. as a cease-to-take flow) then it should act to restrict the temporal extent of flow-related 'stress' to the aquatic ecosystem. Adopting the 50% habitat maintenance flow as a 'cease-to-take' limit means that while the ecosystem will continue to be exposed to periodic 'acute stress' during periods of extreme low-flows, it should limit the risk of 'chronic stress' associated with prolonged and frequent exposure to these conditions.

On this basis, it is recommended that an environmental flow for the South Esk River at Glen Esk should maintain 75% of instream habitat for the benthic invertebrate fauna, and that this is provided on a monthly basis to ensure that seasonal changes in baseflow are preserved. This level of flow should be adopted as the 'sustainable limit' for water allocation, as any allocation of water beyond this is likely to lead to an increased risk of 'chronic' flow-related stress to the aquatic ecosystem. For daily management of water use, the 50% habitat maintenance flow is recommended as providing an appropriate 'cease-to-take' flow. The monthly flows that correspond to these levels are provided in Table B3.

Table B3: Recommended environmental flows and 'cease-to-take' flows for the South Esk River at Glen Esk.

MONTH	Environmental Flow (75% habitat maintenance flow) ($m^3.s^{-1}$)	Cease-To-Take Flow (50% habitat maintenance flow) ($m^3.s^{-1}$)
Jan	3.92	1.20
Feb	2.58	1.30
Mar	2.18	1.37
Apr	3.05	1.85
May	5.80	2.92
Jun	12.27	5.23
Jul	13.71	8.40
Aug	13.71	10.94
Sep	13.71	11.76
Oct	12.17	6.50
Nov	6.10	2.63
Dec	3.42	1.28

5. *Flood flow analysis*

In contrast to low-flows, 'flood flows' or 'high flows' comprise the majority of the variability in the flow regime of a river. Flow events from this part of the hydrograph include small 'freshes' created by brief rainfall events to 'channel maintenance' events that occur 5-10 times per year, and floodplain inundation events that are commonly perceived as 'major floods' in the landscape. Each of these types of flow events are important in creating and maintaining the form and character of the river (Gippel, 2001), as well as creating a diversity of hydraulic environments that supports instream flora and fauna (see discussion in Biggs *et. al*., 2005; and Thoms, 2006). It is important, therefore, when making judgements about components of the flow regime that are required to sustain river ecosystems, some consideration is made of the characteristics (eg. timing, frequency, magnitude, rate of rise and fall) of these events. To do this, a method called 'high spells' analysis has been used (Marsh *et al.,* 2003).

5.1 High Spells Analysis

High spells analyses, using the RAP software package, were used to examine the nature and timing of flow pulses, which tend to occur several times per year and are not normally considered to be major flow events. This technique involves setting flow thresholds (that are of ecological and/or geomorphological importance) and analysing flow time series' to determine statistics such as their frequency, timing, and duration. Bank-full discharge is one useful threshold for analysis as it is often assumed to control the form of alluvial channels (Gordon, *et. al,* 2004), and is considered to have an important role in 'channel maintenance' and the transport of sediment (Newbury and Gaboury, 1993; Gippel 2001).

It is also important that the needs of instream and fringing macrophyte beds are met, as these have been identified as important environmental values in the lower South Esk river system. As mentioned in the previous section, it is apparent from channel survey data that instream benches and flatter areas that contain macrophyte beds are flooded when streamflow reaches about 6 $m^3.s^{-1}$. This is in agreement with statements made by Davies & Humphries (1996) who suggested that about 75% of macrophyte habitat in the river at 'Glen Esk' and 100% of macrophyte habitat at 'Clarendon' (downstream) is wetted when flows reach about 5 $m^3.s^{-1}$. The 'current' modelled flow data for the 'Glen Esk' reach shows that baseflows frequently exceed this level for long periods of time, particularly in winter and spring.

Because the transect data that was used for this site was taken from prior studies that were focussed on assessing the minimum flow requirements for the river (as discussed earlier), a desktop estimate of bank-full discharge could not be made. From the baseflow separation analysis it is known that baseflow during the winter peaks at about 10-12 $m^3.s^{-1}$ at this location. At reaches upstream, where topographic surveys extended further up the river bank, bank-full discharge was estimated to be about 3-4 times the peak winter baseflow, so for this reach a similar level has been used to approximate bank-full flow. This translates to about 35 $m^3.s^{-1}$.

Two additional high spells analyses were conducted using the 5% exceedance* and 20% exceedance flows as thresholds (Table B4). For these spells analyses, events were defined as those that last for ≥1 day and were classed as independent if there were at least 5 days between the peaks in associated flow events. Natural flow data from the hydrologic model for the South Esk catchment were used as input in these analyses; data from this model are at a daily time-step as 'daily average flow'.

The 20% exceedance flow threshold was used to examine the seasonal frequency and duration of smaller events that could be classified as 'freshes' or 'flushing' flows. In addition to its ecological relevance, the 20% exceedance value was also chosen as it approximates the level of the 'flood harvesting rule' developed by Hydro Tasmania; this is applied at the Llewellyn streamflow monitoring station in the lower South Esk catchment. Under this management rule, additional agricultural abstraction can occur for a 5-day period once flow at Llewellyn exceeds 20-23 $m^3.s^{-1}$ (depending on the season).

* see Glossary in main document for a definition of this term

Table B4 provides both an annual summary as well as a seasonal break-down of the results of these analyses. It is interesting that although the bank-full threshold is only 5 $m^3.s^{-1}$ lower than the threshold used at the downstream reach at 'Neck of Bottle', there are some significant differences in terms of the duration of events. At this site the duration of events exceeding 35 $m^3.s^{-1}$ is approximately 6 days and fairly consistent across seasons. At the 'Neck of Bottle' the duration of bank-full events is closer to 10 days, and there is a much more distinct seasonal variation in the duration of events. This is likely to be due to inflow from the Nile River, which has a relatively steep gradient and is likely to discharge large but short-duration flood events that will reach the 'Neck of Bottle' reach well before runoff from the upper South Esk River.

Events with a 20% exceedance flow threshold occur at this location on average about 9 times per year and have an average duration of about 8 days, while events that over-top the river banks and result in flooding of the riparian zone and floodplain (5% exceedance events) occur on average about 5 times per year. For all three flow thresholds, the duration of events is longest during the winter season. As has been noted at all of the other study reaches, the few events that occur in autumn are generally larger than those that occur in winter and spring. This reflects the relatively large impact of deep low-pressure systems that tend to develop off Tasmania's northeast coast in autumn and result in fairly significant rainfall events.

The data in Table B5 show the average duration and rates of rise and fall in the hydrograph for the river at Glen Esk. It provides additional information on rates of change in flow that occur, and illustrates that the river responds rapidly to runoff, with shorter durations (and larger rates) of rise in flows in comparison to falls. Whilst these figures are informative, they are most valuable when viewed in conjunction with figures derived for other locations in the river system. It must also be remembered that they have been derived using *daily* time series data, which is the shortest time-step available from the hydrological model for the catchment.

Table B4: Summary of high spells analysis using 'natural' flow data for the South Esk River at Glen Esk. The 20% exceedance threshold (24 $m^3.s^{-1}$) approximates minor 'freshes' or 'flushing' events at this reach, the second threshold (35 $m^3.s^{-1}$) corresponds approximately with 'bank-full' discharge, and the 5% exceedance threshold (75 $m^3.s^{-1}$) approximates over-bank flood events.

	20% exceedence (24 $m^3.s^{-1}$ or 2,074 $ML.day^{-1}$)			Bank-full flow threshold (35 $m^3.s^{-1}$ or 3,025 $ML.day^{-1}$)			5% exceedence (75 $m^3.s^{-1}$ or 6,480 $ML.day^{-1}$)		
	Average frequency	Average duration (days)	Average magnitude ($m^3.s^{-1}$)	Average frequency	Average duration (days)	Average magnitude ($m^3.s^{-1}$)	Average frequency	Average duration (days)	Average magnitude ($m^3.s^{-1}$)
Annual	8.9	8.1	120	8.1	6.0	137	4.5	4.1	211
Spring	2.6	7.3	93	2.3	4.8	103	1.1	3.1	152
Summer	0.8	5.4	95	0.5	4.8	132	0.3	3.6	220
Autumn	1.4	6.8	153	1.2	5.2	168	0.7	4.4	291
Winter	4.4	8.8	133	4.0	6.2	137	2.4	4.0	200

Table B5: Average duration of rise and fall in flow and rates of change in flow, for the South Esk River at Glen Esk.

Statistic	South Esk River at 'Glen Esk'
Mean duration of Rises (days)	3.7
Mean rate of Rise ($m^3.s^{-1}.d^{-1}$)	11.2
Mean duration of Falls (days)	9.5
Mean rate of Fall ($m^3.s^{-1}.d^{-1}$)	7.3

Tables B4 and B5 show the average seasonal distribution, size, duration and rates of change of ecosystem-relevant flow pulses, but flows may also vary between years. Figure B7compares the annual hydrographs for the years 1987 (a dry year) and 1988 (a wet year) along with the two higher flow thresholds used for the spells analysis. The figure highlights that while the majority of high flow events occur during the winter months, outside of this period, events that exceed both flow thresholds can occur at any time. It also illustrates that there is significant inter-annual variability in the duration of events. During 1987, flow exceeded the 5% exceedance flow threshold (75 $m^3.s^{-1}$) twice and only briefly during the winter, while in 1988 flow exceeded this threshold seven times, one of which lasted for 9 days.

The occurrence of bank-full events appears to be linked to baseflow conditions. When consistent rainfall helps maintain higher baseflow, there appears to be more frequent flow events that exceed the bank-full level. This is also likely to extend event durations.

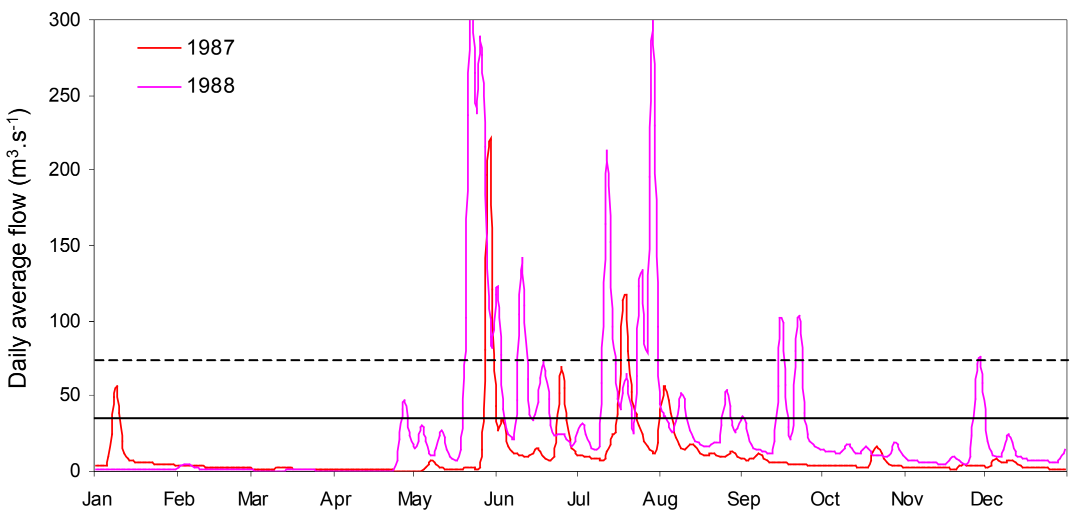

Figure B7: Graph comparing daily average 'natural' flow at Glen Esk on the South Esk River during 1987 and 1988, along with the two upper flow thresholds used for spells analysis.

Given that the current availability of water during the summer is limited, and that extraction of water from the South Esk system is being encouraged during winter, these high spells analyses provide a good basis from which to make recommendations regarding 'environmentally sustainable' allocation of flood water. One of the environmental objectives under the Tasmanian Environmental Flows Framework is to maintain, as far as practicable, the natural pattern of flows. The main environmental and ecological reasons for this are that flooding: provides numerous environmental benefits in terms of nutrient and sediment dispersal, acts to maintain the river form and character, distributes wood and organic material upon which instream fauna rely, and rejuvenates riparian vegetation communities. Bearing these various roles in mind, the following recommendation is made.

5.2 Recommendations for allocation of flood water

It is recommended that the allocation of floodwater be restricted to times when flow at Glen Esk exceeds 35 $m^3.s^{-1}$. Extraction of flood water during this time should not significantly affect flood duration, and to ensure this it is recommended that 600 $ML.day^{-1}$ be made available for extraction for up to 5 days once 35 $m^3.s^{-1}$ is exceeded or until flow falls below the threshold. This volume of water represents about one fifth of the bank-full flow threshold, and is considered to be relatively conservative in terms of protecting the shape of high-flow events and the natural pattern of the flow regime. Considering that events exceeding 35 $m^3.s^{-1}$ occur on average about 8 times per year, this makes about 24,000 ML potentially available on an annual basis. No seasonal boundaries to this rule are proposed.

Under the recommended flood harvesting rules outlined above, all flow events occurring below the 35 $m^3.s^{-1}$ flow threshold are protected. The ecological value of these smaller events is particularly important during prolonged periods of low-flow, as they provide some variability when conditions have been static, and have been viewed as having a role in ‘relieving stress’ on the system (Poff, *et al.*, 1997; Webster, *et al*., 2000). In a dry year, these events may constitute a large proportion of the variability in the flow regime, and it is these events that are most impacted by the proliferation of dams within catchments. In the case of the South Esk catchment, these events are currently provided some measure of protection by the flood harvesting rules (discussed above) that were instituted by Hydro Tasmania following their South Esk Water Management Review in 2003. Under this rule, the combined flow at monitoring sites on the Meander, Macquarie and South Esk rivers must exceed 70 $m^3.s^{-1}$ before flood water can be extracted from any of the 3 river systems.

It should also be recognised that the recommendation made here needs to be considered in the light of similar recommendations made for locations upstream and down the South Esk River system. Any water that is allocated from the catchment above this point needs to be accounted for in downstream management and as part of an overall ‘extraction cap’ for the catchment.

6. Summary

The environmental values that have been identified for the lower South Esk River system relate to the fish and invertebrate fauna inhabiting the river, the aquatic and riparian plant communities within the river corridor and the geomorphic character and processes that maintain instream habitat and productivity. In providing environmental flows to maintain these values, the objective has primarily been to retain natural variability in the flow regime as much as possible. To do this recommendations have been made regarding monthly minimum flow provisions and extraction rules aimed at preserving the magnitude and duration of high flow events.

Monthly minimum flows have been recommended with the aim of maintaining sufficient habitat to maintain benthic fauna and the fish community, and these may be incorporated into the Water Management Plan for the catchment in the form of allocation limits and cease-to-take triggers. Although the primary aim has been to assist with the management of agricultural water extraction during the irrigation period (October to April), data has been provided that covers the rest of the year, and should guide the 'winter' allocation of water.

Basic rules have been recommended regarding the extraction of water during times of flood, and these need to be considered in tandem with rules for water extraction that presently exist as part of Hydro Tasmania's water management process.

It is anticipated that these recommendations will preserve the natural character of the flow regime sufficiently to maintain the freshwater values that have been identified for the lower South Esk River and sustain the ecosystem into the future.